

Lighting Retrofit Considerations

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INTRODUCTION

There are many opportunities to improve the performance of existing lighting systems in which the power and energy use can be reduced while maintaining or improving the lighting quality. Too often, lighting retrofits do not meet their expectations because the decision making criteria were base solely upon economics. Furthermore, some economic analysis are wanting because of the lack of comprehension of the performance of commonly used lighting equipment or are based upon the exaggerated claims of the manufacturers of energy saving and energy efficient lighting components. That is, some equipment is energy saving due to lowering light levels, however, there may be an improvement in efficiency due to thermal effects and not due to action of the equipment. This is detrimental in analysis when comparing different retrofit strategies when these factors are not understood. Often, we are convinced that occupants will not "notice the change in light level," however, even if the change does not invoke a response it is possible that productivity may be impacted, or the salability of the space may suffer. This report will attempt to address the above issues to assist the decision makers in reaching a sound decision with a lighting system that meets their needs. The considerations and information that follows will provide a guideline for evaluating and comparing different retrofit strategies.

We will confine ourselves to the consideration of retrofitting fluorescent systems in commercial or industrial spaces. Data presented represents performance data measured in our laboratory.

FUNDAMENTAL CONSIDERATIONS

Besides assessing the retrofit based upon the cost of lighting equipment, the decision maker should consider the following:

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| i) illuminance level targets | iv) system performance, thermal effects |
| ii) long term lighting goals | v) audits |
| iii) lighting maintenance | vi) installation. |

Illumination Targets

One of the major flaws that most retrofits encounter is specifying the illuminance level based upon the existing illumination in the space. Spaces designed over eight years ago had light levels based upon pre-1981 recommended values by the Illuminating Engineering Society (IES) which have since been revised. If a lighting system in-place has aged, the initial luminance level will have decreased approaching the specified maintained levels due to the normal lamp lumen and dirt depreciation. Thus, any new installation of equipment based upon the present illuminance levels will continue to depreciate with time falling below the proper maintained illuminance level.

The selection of illumination level should be based upon the most recent recommendations by the IES taking into account the task difficulty and the occupants age. Retrofit applications have an advantage over new construction in applying IES recommendations since visual tasks and the age of occupants in the space are known. The IES values are the lighting maintained values and specified illuminance should be adjusted to allow for the normal depreciation factors.

It is common to hear and read about advice provided by vendors as to the proper light level such as "they will hardly notice the reduction in light level." Proper light levels for particular tasks have been a source of conflict within the IES and recommendations from novices should be treated with caution. The important point is not the fact that people do not notice the decreased light levels, but that the lower light levels over a long period of time may negatively influence the occupants comfort and productivity, reducing their speed and accuracy. Adhering to the above suggested selection process, could possibly indicate a reduction in illuminance level since some of latest IES recommendations are well below previous recommendations.

Illuminance levels before and after the retrofit should not be compared visually since the human eyes response to light renders such comparisons subjective. Measurement of the illuminance level should be conducted carefully with a suitable photometer. Since some retrofits alter the distribution from a fixture, measurements should consist of several readings at different positions with respect to the lighting fixtures to obtain a good average value.

Long Term Goals

Many retrofits are initiated in some portion of an entire facility and may involve employing different lamps or ballasts than are currently in-place. The choice of lighting equipment should consider the long term lighting objectives of the facility. This will permit other areas to be retrofit in harmony with the initial retrofit at a later period when funds or time become available. There should be some coordination with the maintenance staff such that the inventory of lamps and ballasts be

minimized. A good retrofit application may eventually, be unintentionally altered after a lamp failure by the maintenance crew replacing the burnt out lamp with a different type of lamp that is in stock. The replaced lamp may have a different color temperature altering the color perception within the space, reducing efficacy and illuminance level.

Lighting Maintenance

It is generally an excellent idea when a major retrofit is planned to coordinate it with lighting maintenance. That is, the walls and fixtures should be cleaned and the space relamped if the retrofit does not specify the use of different types of lamps. This maintenance procedure will result in an increased illumination level which should not be attributed to any additional equipment that is being installed. With the space in this condition, the specified illumination level must be the initial light level which will exceed the measured illuminance level prior to the maintenance.

Thermal Effects

In most fluorescent fixtures, the lamps are operating well above their optimum temperature (40°C). The light output and efficacy of the system decreases at the higher temperatures by as much as 10 to 20 percent. It is important to recognize that when the number of lamps in a fixture is reduced or the power to each lamp is reduced, the remaining lamps will generally operate at a lower temperature and be more efficacious with increased light output. In a cold environment, the remaining lamps may operate below the 40°C temperature which would result in a reduction in efficacy and light output. The latter effect could result in failure to start the lamps or visible striations. The change in efficacy of the lamps or systems for retrofits may be wholly or in part due to the reduction of lamp wall temperature. Figure 1 shows a typical curve of the variation in the light output and efficacy for a fluorescent lamp as a function of lamp wall temperature. Thus, it would be prudent to consider the lamp wall temperature of the lamps in-place and the resulting changes after the retrofit.

Audits

Many building operators follow the recommendations of energy auditors that volunteer their services, e.g., utility or equipment representatives, or are selected paid consultants. The building operator must carefully review the recommendations since equipment representatives will tend to be partial to their own products. The utility representatives and consultants are independent but they may be energy generalists. They may not be sufficiently expert in the art and science of lighting to provide all the possible available retrofit options. It may be wise to supplement the audit and recommendations with advice from a lighting designer or engineer specializing in energy assessments.

Installation

One of the key elements of lighting equipment for a retrofit is minimizing installation costs. Relamping is the simplest, requiring at most opening a fixture. Delamping, requires opening the ballast panel to disconnect the ballast from the mains. Ballast and current limiter retrofits require rewiring these products in the fixture. Specular reflectors for fixtures require repositioning of the sockets and securing the reflector. Controls require hard wiring the system in the circuit. The choice of any particular type of retrofit should consider the effort and cost in properly installing the equipment. Retrofits that require excessive rewiring also cause down-time in the operation of the work place.

RETROFIT OPTIONS

Relamping Fluorescent Lamps

Table I lists several fluorescent lamps in common use providing a range of options (light output, color and efficacy) for possible retrofits. The reader should treat the values of these lamps with caution since they are the values obtained measured under standard American National Standards Institute (ANSI) conditions; i.e., the values are near to the lamps optimum performance. These are the same values found in the lamp manufacturers catalogs. The row below each lamp type shows the performance of a two lamp-ballast system in open air at 25°C ambient temperature. Notice the light output is not twice the single lamps rated value since the light output is reduced by the ballast factor of the particular lamp-ballast combination. The 34 watt and 40 watt lamps were all operated with the same standard Certified Ballast Manufacturers (CBM) ballast. The table lists the ballast factors and shows that the same ballast will have a different ballast factor for a different lamp type, e.g., argon filled (40 watt) and krypton filled (34 watt). As shown in the following sections, there were other significant changes in the relative performance of lamps when they became part of the total system (lamp-ballast-fixture).

One should notice for the F40, T-12 lamps the only significant increase in the lamp efficacy was due to the change in the efficiency of the phosphor coating. The lite white (LW) phosphor compared with the cool white (CW) results in a reduction of color rendering. The T-8 lamps employ narrow band phosphors which are both more efficient and had higher color rendering. The narrow band rare earth phosphors also had reduced lamp lumen depreciation which is the reason it was used for the higher power loaded T-8 lamp.

The column of the relative changes of power, light and efficacy is with respect to the standard 40 watt F40 lamp and lamp-ballast system.

Lamp, Ballast, Fixture Systems

We will examine how the above lamps operate in an enclosed ceiling mounted four lamp fixture for a variety of retrofit strategies. All discussions will be with respect to 40 watt F40, T-12 CW lamps operated with a standard magnetic ballast.

Delamping: Table II lists changes in the performance of a delamped four lamp 40 watt F40, T-12 CW lamp-ballast system in an enclosed ceiling mounted luminaire at a 70°F room ambient temperature. The table shows that the light output and power input do not decrease by 50 percent but by 45 and 48 percent, respectively. The efficacy of the remaining two lamp-ballast system increases by 7 percent after the delamping (the ballast that is delamped is disconnected from the circuit). The last column listing the minimum lamp wall temperature (MLWT), shows that the reason for this change is the decrease in the MLWT from 57° to 50°C. If LW, 40 watt lamps are used in place of the cool white lamps, the decrease in light level is 39 percent.

The reader should recall the above when analyzing lighting equipment that reduce light levels in a luminaire. The above shows there will be an efficacy and light output increase solely due to the thermal effect.

Lamp System Replacement: The results when a four lamp 40 watt, F40 T-12 CW system is replaced by an energy saving or energy efficient system is shown in Table III. The relative performance between the 34 watt and 40 watt lamp systems is different than in Table I where the lamps were at the same lamp wall temperature conditions. In the four lamp fixture, the lamp wall temperature of the 34 watt system is 8° cooler resulting in a power reduction of 9 percent compared to the 40 watt F40 lamp system. This results in a decreased light level of 7 percent and 1 percent for the CW and LW 34 watt systems, respectively. Thus, by virtue of these thermal effects the 34 watt energy saving system becomes more efficient but the reduction in power is only 9 percent instead of the expected 17 percent. With the LW phosphor lamp having the reduced color rendering, there is only a 1 percent decrease in light level.

Replacing the 40 watt system with a more efficient lamp system can be achieved with a 40 watt LW system, or the recently introduced T-8 lamp system with a core-coil, or an electronic ballast. The 40 watt LW system maintains its improved efficacy and operates the lamps at the same lamp wall temperature. The T-8 lamp systems have the highest system efficacy reducing power demand by 22 and 20 percent for the core-coil and electronic ballast. The high frequency T-8 system provides 25 percent more light. The systems that provide higher light output are excellent candidates for compound retrofits, maintaining their illumination level with a delamping strategy which reduces light level.

Current Limiters: A common retrofit strategy is the use of a current limiting device that reduces the input current to a standard core-coil ballast system. There are systems that reduce the power and light by 20, 30 or 50 percent. Table IV shows the effect of a 40 watt lamp system with a 30 and 50 percent system. Under the same lamp wall

temperature conditions, the power and light output would be reduced 30 or 50 percent. Due to the reduced lamp wall temperature the reduction in power and light is less than 30 and 50 percent and the system efficacy is increased by 2 and 4 percent. Clearly, the efficacy improvement is due to thermal effect and not the current limiter.

When the same tests are run in open air, where the lamps (with and without the current limiter) are at the same lamp wall temperature, the system efficacy does not change. This again shows the current limiter device does not cause the efficacy increase one observes in the enclosed fixture. In fact, the 50 percent current limiter reduces the lamp wall temperature 5°C below optimum, resulting in a 6 percent decrease in efficacy. This demonstrates a retrofit that drives the lamp wall temperature below the optimum temperature.

The open air result with the 50 percent current limiter, points out a potential problem when used with 34 watt lamps. Reducing the lamp current of the 34 watt lamps could reduce the lamp wall temperature well below the optimum temperature. At these lower lamp wall temperatures, starting and severe flickering problems may result.

Specular Reflectors: Fluorescent fixtures can be made more efficient by the insertion of a suitably shaped specular reflector. The specular reflector material types are aluminum, silver and multiple dielectric film mirrors. The latter two have the highest reflectivity while the aluminum reflectors are less expensive. In retrofits, the vendor generally recommends it is possible to remove two lamps from a four lamp fixture and still obtain the same light output. Table V shows the results if one installs a specular reflector in a fixture with standard four lamp, 40 watt F40 lamps and removes two lamps. Measurements show the fixture efficiency with higher reflectance specular reflectors (silver or dielectric films) is improved by 15 percent compared to a new fixture with standard diffuse reflectors. The table distinguishes the reflectors improved fixture efficiency due to the specular reflector and the decrease in the lamp wall temperature. In Table II, the change in the lamp-ballast-fixture performance is shown for a fixture without the specular reflector with two and four lamps. While the two lamp output is decreased by 44 percent with the improved fixtures optical efficiency, the light level is 35 percent less than the original four lamp fixture. The reduction in power is 48 percent, slightly less than the 50 percent one would intuitively expect. If we replace the 40 watt CW lamps with 40 watt LW lamps, the light loss is 29 percent less than the four lamp fixture without the specular reflector.

This distribution change is better described by the change in candle power distribution. Specular reflectors tend to concentrate more light downward with reduced light at high exit angles. This increases the light modulation in the space which is the reason several light readings at different sites about the fixture are required for determining the average illuminance. The increased downward component of candle power may increase the potential for reflected glare from horizontal surfaces.

When considering reflectors, information should be obtained on the new candle power characteristics. With this information a lighting designer or engineer, can estimate the potential changes in modulation and reflected glare.

Many comparisons of this retrofit are made with older fixtures, with degraded reflecting surfaces, and changing the types of lamps, say, from four 34 watt F40 lamps to two 40 watt F40 lamps. One should ascertain the performance of the components being retrofit to properly assess both the cost effectiveness and the specified illumination level target. Do not rely on your visual perception to evaluate a retrofit but employ careful measurement with a reliable photometer.

SUMMARY

Today there are many options available for an effective lighting retrofit that reduce energy consumption and maintains the lighting needed for the visual tasks. We have considered retrofits concerned with fluorescent lamp systems. While the driving force to initiate the retrofit is reducing power demand (and energy use), other factors discussed must be considered to obtain satisfaction. We have shown that assessment of retrofit options are not simple and should not be based solely upon components data found in catalogs. Understanding the components performance in a system is mandatory and requires special knowledge; real system performance data is needed to assess the cost effectiveness of the retrofit options. There are lighting designers and engineers that have accumulated this expertise and have incorporated it in their lighting design repertoire. By thorough evaluation of these options, an appropriate lighting retrofit can be obtained and pay handsome returns.

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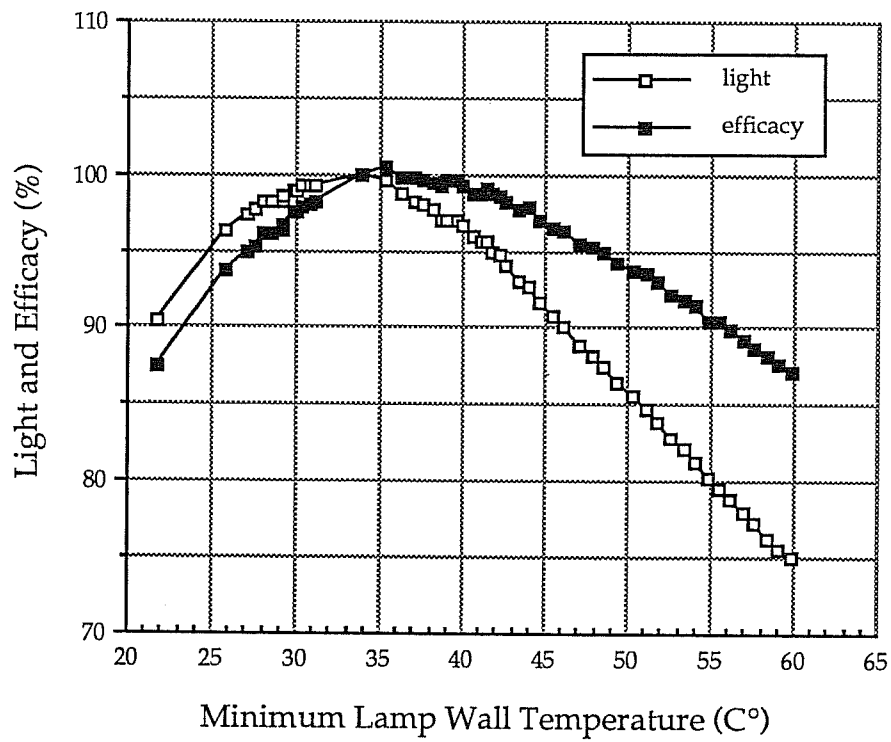


Figure 1. Variation of Light Output and Efficacy of a Standard Two-Lamp 40 Watt F40 T-12 Rapid Start Fluorescent System

TABLE I
RATE FLUORESCENT LAMP AND LAMP-BALLAST OPTIMUM PERFORMANCE

Lamp System	Power W	Light Output lm	Efficacy lm/W	Ballast Factor	Relative		CRI
					Power	Light	
1. 40W F40 T-12/CW Two lamp-ballast system*	40	3150	79	0.95	1.00	1.00	67
	95	5990	63		1.00	1.00	67
2. 40W F40 T-12/LW Two lamp-ballast system*	40	3450	86	0.95	1.00	1.10	51
	95	6560	69		1.00	1.10	51
3. 34W F40 T-12/CW Two lamp-ballast system*	34	2750	81	0.87	0.85	0.87	67
	79	4790	61		0.83	0.80	67
4. 34W F40 T-12/LW Two lamp-ballast system*	34	2925	86	0.87	0.85	0.93	51
	79	5090	64		0.83	0.85	51
5. 32W F032 T-8/41K Two lamp-ballast system**	32	2900	91	0.92	0.80	0.92	85
	71	5360	75		0.75	0.89	85
6. 32W F032 T-8/41K*** Two lamp-ballast system****	32	3190	100	0.91	0.80	1.01	85
	65	5820	90		0.68	0.97	85

* Standard core-coil CBM ballast.

** Core-coil ballast for F032 lamp.

*** High frequency operation.

**** Electronic ballast.

TABLE II
DELAMPING 40 WATT ENCLOSED FOUR LAMP FIXTURE

<u>Lamp-Ballast System</u>	<u>Power</u> <u>W</u>	<u>Light Output</u> <u>lm</u>	<u>Efficacy lm/W</u> <u>System</u>	<u>Power</u>	<u>Relative</u> <u>Light</u>	<u>Efficacy</u>	<u>Lamp Wall</u> <u>Temp. (°C)</u>
Two 2-lamp 40W F40 T-12/CW System	169	9340	55	1.00	1.00	1.00	57
One 2-lamp 40W F40 T-12/CW System	88	5210	59	0.51	0.56	1.07	50
One 2-lamp 40W F40 T-12/LW* System	88	5710	65	0.52	0.61	1.18	50

* Replace the CW 40 watt lamp with LW 40 watt lamp.

TABLE III
REPLACE 40 WATT LAMP IN A FOUR LAMP ENCLOSED FIXTURE

Lamp-System	Power W	Light Output lm	Efficacy lm/W System	Efficacy lm/W Lamp	Power	Relative Light	Efficacy	Lamp Wall Temp. (°C)
Two 2-lamp 40W F40 T-12 CW System	169	9340	55	70	1.00	1.00	1.00	57
Two 2-lamp 40W F40 T-12 LW System	169	10,230	61	77	1.00	1.10	1.11	57
Two 2-lamp 34W F40 T-12 CW System	153	8710	57	76	0.91	0.93	1.04	49
Two 2-lamp 34W F40 T-12 LW System	153	9270	61	81	0.91	0.99	1.11	49
Two 2-lamp 32W F40 T-12 41K System	131	9330	71	89	0.78	1.00	1.29	49
Two 2-lamp 32W F40 T-12 41K System*	135	11,650	86	96	0.80	1.25	1.56	49

* High frequency system.

TABLE IV
CURRENT LIMITERS ON FOUR LAMP ENCLOSED FIXTURE

<u>Lamp-System</u>	<u>Power</u> <u>W</u>	<u>Light Output</u> <u>lm</u>	<u>Efficacy lm/W</u> <u>System</u>	<u>Power</u>	<u>Relative</u> <u>Light</u>	<u>Efficacy</u>	<u>Lamp Wall</u> <u>Temp. (°C)</u>
Two 2-lamp 40W F40 T-12 CW System	169	9340	55	1.00	1.00	1.00	57
• With 30% current limiter	128	7290	57	0.76	0.78	1.04	49
• With 50% current limiter	93	5570	60	0.55	0.60	1.09	44
2-Lamp 40W F40 T12/CW System (Open Air)	95	5990	63	1.00	1.00	1.00	40
• With 30% current limiter	63	3980	63	0.66	0.66	1.00	38
• With 50% current limiter	46	2710	59	0.73	0.45	0.94	35

TABLE V
SPECULAR REFLECTOR INSERTS, DELAMPING IN ENCLOSED FOUR LAMP FIXTURE

<u>Lamp-System</u>	<u>Power W</u>	<u>Light Output (lm) Lamps</u>	<u>Optical Fixture Efficiency (%)</u>	<u>Relative</u>		<u>Efficiency lm/W</u>	
				<u>Power</u>	<u>Light</u>	<u>Lamps System</u>	<u>Fixtures Output</u>
Two 2-lamp 40W F40 T-12 CW System	169	9340	65	1.00	1.00	55	36
2-Lamp 40W F40 T-12 CW System - specular reflector	88	5210	76	0.52	0.65	59	45
2-Lamp 40W F40 T-12 LW System - specular reflector	88	5710	76	0.52	0.71	65	49